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Turbulence modelling in the two-dimensional vortex-in-cell method

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ABSTRACT

In bridge aerodynamics, particle based vortex methods are used extensively to calculate the aerodynamic forces and flow field around bridge cross sections due to its stability and efficiency. So far the applied vortex methods have modelled the flow without employing an explicit model for unresolved turbulence scales. The hybrid vortex-in-cell (VIC) method offers a highly efficient particle-mesh algorithm that combines Lagrangian and Eulerian schemes to discretise different parts of the governing equation and thereby exploits the strength of each scheme. One of the benefits of the VIC method is its ability to efficiently solve transport equations. This is used in the present study to implement transport based turbulence models. The main focus of the study is implementing the Spalart-Allmaras (SA) turbulence model [1] by an unsteady RANS approach. Additionally, a selection of LES models have been implemented, including the Lagrangian dynamic eddy viscosity (LDEV) model [2] and a transport model for the kinetic turbulent energy. Even though 2D LES turbulence modelling lack physical merit, due to the non-existing vortex stretching, reasonable results using LES have been presented in literature e.g. [3]. The 2D LES models are however only used as a basis of comparison and as a step towards a future 3D implementation. The applied 2D VIC method is a further development of of the multi-resolution VIC method presented in [4], where a novel high order Poisson solver is implemented based on fast Fourier transforms subject to free space boundary conditions. By exploiting the linearity of the Poisson equation, high grid resolution is achieved using particle and mesh patches of different resolution. Solid boundaries are implemented by a Brinkman penalisation [5] using an explicit split-step algorithm. The turbulence models are implemented by solving the eddy viscosity transport equation similarly to the vorticity equation by convecting the eddy viscosity along with the particles.

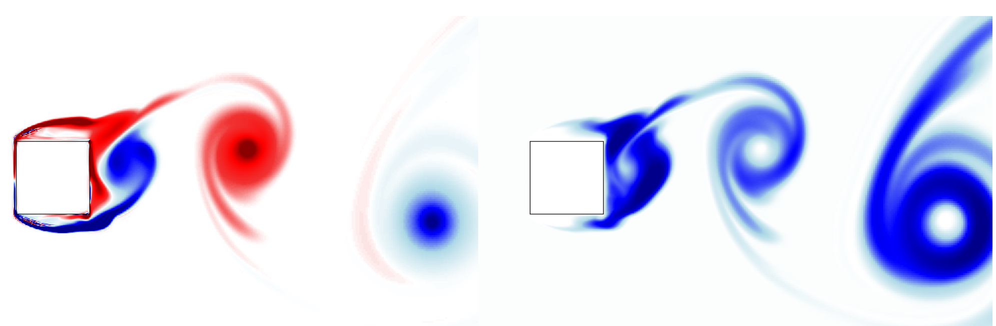

Figure 1: The simulated flow around a square cylinder using the Spalart-Allmaras turbulence model with an inflow condition of the eddy viscosity. Left: vorticity field. Right: modelled eddy viscosity.

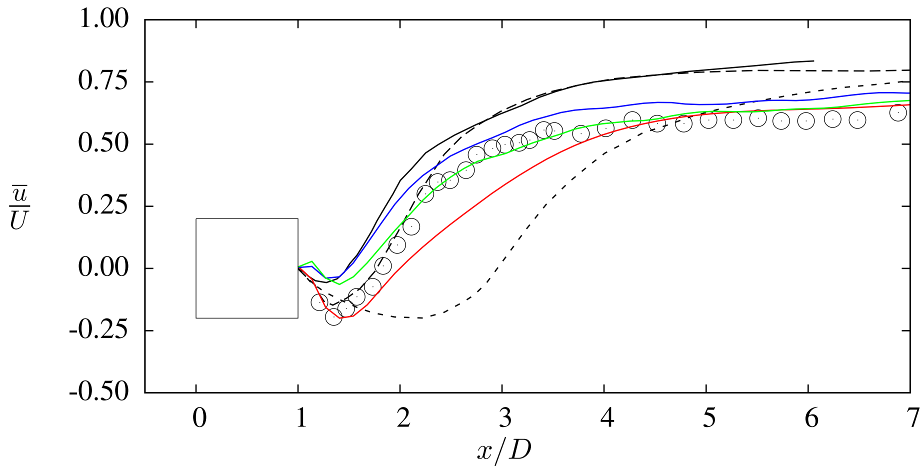

Figure 2: Wake profile of the time averaged horizontal velocity $\overline{u}$ for the different models. Present results: ——: SA, ——: LDEV, ——: turbulence energy equation. Experimental results: ○ Lyn et al. [7]. Other 2D numerical results: ——: LES Bouris et al. [3], - - - - and – – – –: RANS Bosch et al. [6]

As shown in figure 1, the implemented turbulence model is validated by simulating the highly separated flow around a square cylinder at $\text{Re} = UD/\nu = 22.000$, where D is the height/length of the cylinder and ν is the kinematic viscosity of the fluid. The resulting mean flow shows an overall good agreement with experimental data [7] as seen in fig. 2. The SA model captures the mean back-flow in the near wake of the cylinder while still maintaining a good result in the far wake. The calculated drag coefficients is found to be approximately 10% higher than what is reported in experimental publications. The calculated vortex shedding frequency of the SA model is found to be around 20% too high. This is believed to be caused by the averaging of a general vortex shedding pattern which leads to a single vortex shedding instead of a double pairwise shedding, which is observed in experiments. The LES models (not shown) are found to capture the pairwise vortex shedding pattern and identify multiple shedding frequencies.

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